4.2.12 Constituent Material Model Identification:

Purpose: To select the model for the fiber and matrix constituents.

***FIBER**
NFIBS=*nfibs*

The following new line is to be repeated for each fiber (nfibs):
NF=nf_f **MS=*ms_f*** MF=$ncmd_f$ NDPT=*dpt* ***TEMP=*****mtemp** MAT=mat_f &
IFM=**ifm** ***D=d_1,d_2,d_3***

***MATRIX**
NMATX=*nmatx*

The following new line is to be repeated for each matrix (nmatx):
NM=nm_m **MS=*ms_m*** MM=$ncmd_m$ NDPT=*dpt* ***TEMP=*****mtemp** MAT=mat_m &
IFM=**ifm** ***D=d_1,d_2,d_3***

***MONOL (available for laminate option only)**
NMON=*nmon*

The following new line is to be repeated for each monolithic material (nmon):
NMO=nmo_{iso} MS=ms_{iso} MMO=$ncmd_{iso}$ NDPT=*dpt* ***TEMP=*****mtemp** &
MAT=mat_{iso} ***IFM=*****ifm**

%

Where:

nfibs: - number of different fibers

nmatx: - number of different matrices

nmon: - number of different monolithic layers

nf_f: - fiber material designation number running from 1 to *nfibs*, sequentially.

nm_m: - matrix material designation number running from 1 to *nmatx*, sequentially.

nmo_{iso}: - monolithic material designation number running from 1 to *nmon*, sequentially.

msf: - fiber material system ID (**required only when using laminate option**)

***ms_m*:** - matrix material system ID. (**required only when using laminate option**)

ms_{iso}: - monolithic material system ID

ncmd: - material model identifier for either fiber, matrix or monolithic layer:
1 = Bodner-Partom Model
2 = Modified Bodner-Partom Model
3 = Robinson Viscoplastic Model
4 = Generalized Viscoplastic Potential Structure (GVIPS) Model
6 = Transversely Isotropic Elastic Model (2-3 isotropic plane)
7 = Transversely Isotropic GVIPS Model (TGVIPS)
9 = Local Transversely Isotropic Elastic Model

99 = User defined model (see note at the end of section for special format instructions)

mat: - material identification letter for either fiber or matrix, selected from material database, see **Table II**.

☞ **Note: By specifying MAT=U allows the user to specify the material constants according to the formats specified below.**

dpt: - flag indicating whether material constants should be temperature independent or temperature dependent
1 = Temperature Independent
2 = Temperature Dependent

mtemp: - the constant temperature at which material properties are to be taken (**only required for dpt= 1 and when using database properties)**

ifm - flag indicating whether material properties will be read from input file or taken from a user defined function (provided in the USRFUN subroutine) **ONLY NEEDED when MAT=U**.
1 = read from input file
2 = functional form taken from USRFUN routine

$\mathbf{d_i}$: - direction vector defining the normal to the plane of local isotropy (**only required for ncmd = 3, 7 or 9)**

☞ **Note:** If **modid=1** (Double periodicity) and one desires transverse isotropy using **ncmd= 3,7 or 9** then the strong material direction **must** be specified in the 1-direction.

☞ **Note:** Additional Input is required if the ❋**DAMAGE** (section **4.2.6**) option is invoked

The following additional data is entered on a **new line**:

ANG=θ BN=b BP=b' OMU=ω_u OMFL=ω_{fl} OMM=ω_m ETU=η_u &
ETFL=η_{fl} ETM=η_m BE=β A=a SFL=σ_{fl} XML=*M* SU=σ_u SK=*sk* %

where:

sk:

= 1 skip fatigue damage calculations for this material
= 0 perform fatigue damage calculations

The remaining constants are described in section **3.5**

☞ **Note:** In addition, for FL=1 (micro failure criteria) in section **4.2.6**, the additional data is also required:

T=*ss* IC=*icomp* V=*val*

ss:
1 - stress
2 - strain

comp:
1 - component 11
2 - component 22
3 - component 33
4 - component 23
5 - component 13
6 - component 12

val - value of failure stress or strain (depending on value of *ss*)

Example 1: select 1 fiber, SCS-6, and 1 matrix material, TIMETAL 21S, both read from database; i.e., SCS-6/TIMETAL 21S composite system

❋FIBER
NFIB=1
NF=1 MF=6 NDPT=1 TEMP = 23 MAT=D %

❋MATRIX
NMATX=1
NM=1 MM=4 NDPT=1 TEMP = 23 MAT=A %

☞ **Note:** See **Section 3.3** for a mathematical description of each material model.

Example 2: (select 2 matrix materials; material 1: Boron, read from database, material 2: user supplied properties)

❋MATRIX
NMATX=2
NM=1 MM=6 NDPT=1 MAT=U IFM=1 EL=E_L, E_T, ν_A, ν_T, &
G_A, α_A, α_T VI= D_0, Z_0, Z_1, m, n,q K= κ_A, κ_T
NM=2 MM=1 NDPT=1 MAT=U IFM=1 EL=E_L, E_T, ν_A, ν_T, &
G_A, α_A, α_T VI= D_0, Z_0, Z_1, m, n,q K= κ_A, κ_T**%**

☞ **Note:** The κ_A, κ_T data is only required if the ❋**COND** keyword has been used; where κ_A, κ_T are the axial and transverse thermal conductivities, respectively.

☞ **Note: Required Material constants for each model is as follows**:

Bodner-Partom: *ncmd* = 1

Elastic:	Inelastic:
EL=E_L, E_T, ν_A, ν_T, G_A, α_A, α_T	VI= D_0, Z_0, Z_1, m, n,q

Modified Bodner-Partom: *ncmd* = 2

Elastic:	Inelastic:
EL=E_L, E_T, ν_A, ν_T, G_A, α_A, α_T	VI= D_0, Z_0, Z_1,Z_2, Z_3, m_1 m_2, n, a_1, a_2, r_1, r_2, Dm_1, Dm_2

Robinson Viscoplastic: *ncmd* = 3

Elastic:	Inelastic:
EL=E_L, E_T, ν_A, ν_T, G_A, α_A, α_T	VI= n, m, μ, κ_T, β, R, H, $\hat{G}_0$, η, ω

Directions:
D=d_1, d_2, d_3

GVIPS: *ncmd* = 4

Elastic:	Inelastic:
EL=E, ν, α	VI= μ, κ, R_α, R_κ, B_0, B_1, L_0, L_1, m, n, p, q, w, z_0

Elastic Model: *ncmd* = 6
EL=E_L, E_T, ν_A, ν_T, G_A, α_A,α_T

TGVIPS: *ncmd* = 7

Elastic:	Inelastic:
EL=E_L, E_T, ν_A, ν_T, G_A, α_A, α_T	VI= κ, n, μ, m, β, R, H, G_0, ω, η

Directions:
D=d_1,d_2,d_3

Transversely Isotropic Elastic Model: *ncmd* = 9

Elastic	Directions:
EL=E_L, E_T, ν_A, ν_T, G_A, α_A,α_T	D=d_1,d_2,d_3

Table II. MAC/GMC Material Constant Database

Model	Material	Temperature Dependent ?	Units	*mat*
Bodner-Partom	Aluminum (2024-T4)	Yes	Pa, sec,^{o}C	A
ncmd = 1	Aluminum (2024-0)	Yes	Pa, sec,^{o}C	B
all properties taken from ref [1]	Aluminum (6061-0a)	Yes	Pa, sec,^{o}C	C
	Aluminum (6061-0b)	Yes	Pa, sec,^{o}C	D
	Aluminum (pure)	Yes	Pa, sec,^{o}C	E
	Titanium (pure)	No	Pa, sec,^{o}C	F
	Copper (pure)	No	Pa, sec,^{o}C	G
Modified Bodner-Partom *ncmd* = 2	TIMETAL 21S	Yes	Pa, sec, ^{o}C	A
Robinson Visco-plastic	Kanthal	No, 600^{o}C	ksi, hr,^{o}C	A
	FeCrAlY	Yes	ksi, hr, ^{o}C	B
ncmd = 3	W/Kanthal (vf=35%)	No, 600^{o}C	ksi, hr, ^{o}C	C
GVIPS *ncmd* = 4	TIMETAL 21S	Yes	ksi, sec, ^{o}C	A
Linear Elastic	Boron	No	Pa, ^{o}C	A
ncmd = 6	SCS-6	Yes	Pa, ^{o}C	B
All properties are assumed isotropic	Tungsten (W)	No	Pa, ^{o}C	C
	Boron	No	ksi, ^{o}C	D
	SCS-6	Yes	ksi, ^{o}C	E
	Tungsten (W)	No	ksi, ^{o}C	F
TGVIPS *ncmd* = 7	Ti-6-4	Yes	ksi, sec, ^{o}C	A
Linear Elastic	T50 Graphite	No	Pa, ^{o}C	A
ncmd = 9	T300 Graphite	No	Pa, ^{o}C	B
Transversely Isotropic	P100 Graphite	Yes	Pa, ^{o}C	C
	T50 Graphite	No	ksi, ^{o}C	D
	T300 Graphite	No	ksi, ^{o}C	E
	P100 Graphite	Yes	ksi, ^{o}C	F

☞ **Note: Warning:** It is the user's responsibility to ensure that **consistent material property units** are being employed within a given problem. Particularly, when mixing database and user supplied material properties.

☞ **Note:** Even if a material model is temperature independent, it can still be used in a nonisothermal analysis (ndpt=2). Its properties will just not vary with temperature.

☞ **Note: Required Format for User Supplied Non-Isothermal Material Constants:** each of the following data statements are on separate lines.

NTP= *ntpts*

TEM= $T_1, T_2, \ldots, T_{ntpts}$

EA= $E_{AT_1}, E_{AT_2}, \ldots E_{AT_{ntpts}}$

ET= $E_{TT_1}, E_{TT_2}, \ldots E_{TT_{ntpts}}$

NUA= $\nu_{AT_1}, \nu_{AT_2}, \ldots \nu_{AT_{ntpts}}$

NUT= $\nu_{TT_1}, \nu_{TT_2}, \ldots \nu_{TT_{ntpts}}$

GA= $G_{AT_1}, G_{AT_2}, \ldots G_{AT_{ntpts}}$

ALPA= $\alpha_{AT_1}, \alpha_{AT_2}, \ldots \alpha_{AT_{ntpts}}$

ALPT= $\alpha_{TT_1}, \alpha_{TT_2}, \ldots \alpha_{TT_{ntpts}}$

V1= $V1_{T_1}, V1_{T_2}, \ldots V1_{T_{ntpts}}$

V2= $V2_{T_1}, V2_{T_2}, \ldots V2_{T_{ntpts}}$

⋮

VN= $VN_{T_1}, VN_{T_2}, \ldots VN_{T_{ntpts}}$

D = d_1, d_2, d_3

☞ **Note:** The total number of viscoplastic constants (V1, V2, V3, ... VN) required for each model are described on the bottom of page 71. **For ncmd=4, three extra lines (V15=** κ_o **V16=** B_o**' V17=** β_κ **) must be added**. Also, D= d_1, d_2, d_3 is only required when ncmd= 3, 7 or 9.

☞ Note: Format for User defined material model (ncmd=99):

Given **User Supplied Isothermal Material Constants**, the following special format is required:

❋FIBER
NFIBS=*nfibs*

The following line is to be repeated for each fiber (nfibs):
NF=nf_f MS=ms_f MF=99 *NDPT=dpt* NPE=*npe* EL=$e_1, e_2, \ldots e_{npe}$ &
ALP= α_A, α_T NPV=*npv* VI=$v_1, v_2, \ldots v_{npv}$ K=κ_A, κ_T %

❋MATRIX
NMATX=*nmatx*

The following line is to be repeated for each matrix (nmatx):
NM=nm_m MS=ms_m MM=99 *NDPT=dpt* NPE=*npe* EL=$e_1,e_2,...e_{npe}$ &
ALP= α_A, α_T NPV=*npv* VI=$v_1,v_2,...v_{npv}$ K=κ_A, κ_T %

Where:

npe: - total number of elastic constants (maximum of 9)

npv: - total number of inelastic constants (model specific, max of 19)

e_1,e_2,.. - elastic constants

v_1,v_2,... - inelastic constants (model specific)

α_A,α_T,... - longitudinal and transverse thermal expansion coefficients

κ_A,κ_T,... - thermal conductivities (if ❋**COND** only)

OR given **User Supplied <u>Non-Isothermal</u> Material Constants:**

❋FIBER
NFIBS=*nfibs*

The following line is to be repeated for each fiber (nfibs):
NF=nf_f MS=ms_f MF=99 *NDPT=2* MAT= U IFM= 1
NPE=*npe* NPV=*npv*

with the following data statements immediately following each material declaration on a <u>separate</u> line.

NTP= *ntpts*

TEM= $T_1, T_2, ..., T_{ntpts}$

E1= $E_{1T_1}, E_{1T_2}, \ldots E_{1T_{ntpts}}$

E2= $E_{2T_1}, E_{2T_2}, \ldots E_{2T_{ntpts}}$

⋮

Enpe= $E_{npeT_1}, E_{npeT_2}, \ldots E_{npeT_{ntpts}}$

ALPA= $\alpha_{AT_1}, \alpha_{AT_2}, \ldots \alpha_{AT_{ntpts}}$

ALPT= $\alpha_{TT_1}, \alpha_{TT_2}, \ldots \alpha_{TT_{ntpts}}$

V1= $V1_{T_1}, V1_{T_2}, \ldots V1_{T_{ntpts}}$

V2= $V2_{T_1}, V2_{T_2}, \ldots V2_{T_{ntpts}}$

⋮

Vnpv= $Vnpv_{T_1}, Vnpv_{T_2}, \ldots Vnpv_{T_{ntpts}}$

KA= $\kappa_{AT_1}, \kappa_{AT_2}, \ldots \kappa_{AT_{ntpts}}$

KT= $\kappa_{TT_1}, \kappa_{TT_2}, \ldots \kappa_{TT_{ntpts}}$

❋MATRIX

NMATX=*nmatx*

The following line is to be repeated for each matrix (nmatx):
NM=nm_m MS=ms_m MM=99 *NDPT=2* MAT=U IFM = 1
NPE=*npe* NPV=*npv*

with the following data statements immediately following each material declaration on a separate line.

NTP= *ntpts*

TEM= $T_1, T_2, \ldots, T_{ntpts}$

E1= $E_{1T_1}, E_{1T_2}, \ldots E_{1T_{ntpts}}$

E2= $E_{2T_1}, E_{2T_2}, \ldots E_{2T_{ntpts}}$

⋮

Enpe= $E_{npeT_1}, E_{npeT_2}, \ldots E_{npeT_{ntpts}}$

ALPA= $\alpha_{AT_1}, \alpha_{AT_2}, \ldots \alpha_{AT_{ntpts}}$

ALPT= $\alpha_{TT_1}, \alpha_{TT_2}, \ldots \alpha_{TT_{ntpts}}$

V1= $V1_{T_1}, V1_{T_2}, \ldots V1_{T_{ntpts}}$

V2= $V2_{T_1}, V2_{T_2}, \ldots V2_{T_{ntpts}}$

⋮

Vnpv= $Vnpv_{T_1}, Vnpv_{T_2}, \ldots Vnpv_{T_{ntpts}}$

KA= $\kappa_{AT_1}, \kappa_{AT_2}, \ldots \kappa_{AT_{ntpts}}$

KT= $\kappa_{TT_1}, \kappa_{TT_2}, \ldots \kappa_{TT_{ntpts}}$

☞ **Note:** Required material user subroutines; see **Example K** for details on how they integrate together

USRFUN: - Routine that defines functional form for material properties
Required when: ifm=2 and mat=U

USRFORMDE*:* - Routine that forms the stiffness matrix. Required when ncmd = 99

USRCPEVAL: - Routine that defines the time derivative of the stiffness matrix. Required when:
a) **ifm=2 and mat=U**
b) **ncmd=99 AND ifm=1 AND ndpt=2**